Pressure Oscillations in Hybrid Rocket Motors

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Beginning in 1992, a joint government-industry program has been conducted at MSFC to develop hybrid rocket motors. Hybrid rocket motors combine an inert solid fuel grain with a gaseous or liquid oxidizer in an effort to realize the benefits of both liquid and solid rocket motors. This joint effort, funded by both private and public moneys, is known as the Joint Independent Research and Development Hybrid Program.

One of the most significant findings to date has been the recurrence of motor-pressure oscillations under various operating conditions. These oscillations are not unstable in the sense of increasing amplitude, but—in worst-case conditions—they have spiked to double the motor operating pressure before returning to a more uniform pattern. Joint development members MSFC, Thiokol Space Operations, the Rocketdyne Division of Rockwell International, and Lockheed Martin Astronautics are performing extensive research to determine the causes of the observed oscillations and methods for controlling them.

A significant body of research has been devoted to the problem of flame stabilization in ramjets. Two factors that affect flame stabilization are the temperature of incoming gas and the flow field at the entrance to the fuel grain. Because of the similarity of hybrids and ramjets, it is reasonable to assume the same factors will affect flame stability in hybrid rocket motors. The similarities between hybrids and ramjets and results from an earlier industry independent research and development program provided the basic hypothesis for this program: namely, flame stabilization at the entrance to the fuel grain is required for smooth hybrid motor combustion. This program is investigating the effects of liquid-oxygen flow rates, head-end flow fields, and liquid-oxygen vaporization on hybrid pressure oscillations. Each of these factors is thought to directly affect establishment of a stable flame at the entrance of a fuel-grain port.

To date, all program effort has used a liquid-oxygen-fed motor (24 inches in diameter). Figure 53 is a schematic for the motor. The major case components are forward closure, vaporization chamber, grain sections, mixing chamber, and aft closure. The motor is designed to allow for the lengths and configurations of each of its components to be varied.

All tests use identical, monolithic, seven-port fuel grains (108 inches in length). A typical test duration is 10 seconds. Parameters that have been varied in the program include liquid-oxygen flow rate (10, 20, and 40 pounds mass per second), injector flow pattern (axial and solid cone), fuel configuration in the vaporization chamber (domed or domed with fins), and the degree of coupling between the motor and the feed system.

In tests for which the feed system has not been isolated from the motor, organized 5- to 10-hertz oscillations have occurred. When there has been a high degree of isolation between the motor and the feed system, the motor has operated with only minimal combustion roughness. The isolation has been provided for each by an orifice or venturi close to the injector and by a high-pressure drop across the injector. In each case, the result was a disappearance of the oscillations. Examples of oscillatory and nonoscillatory behavior are shown in figures 54 and 55.

To date, the motor has operated without oscillations at all flow rates and with both finned and nonfinned

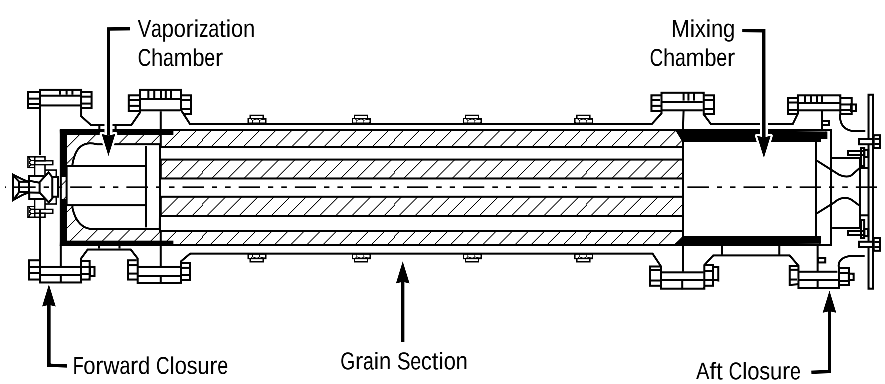

FIGURE 53.—24-inch motor configuration.

head ends. At fluxes tested thus far (up to 0.73 pound mass per second per square inch), the vaporization chamber fuel configuration has not had a significant impact on the smoothness of the pressure trace. Future testing will push the flux to 1.0 to determine the effect on combustion. These future efforts will be integrated to form a part of the Hybrid Propulsion Demonstration Program.

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Carpenter, R.L.; Boardman, T.A.; Claflin, S.E.; and Harwell, R.J. July 1995. Hybrid Propulsion for Launch Vehicle Boosters: a Program Status Update. Paper 95–2688, 31st American Institute of Aeronautics and Astrophysics/American Society of Mechanical Engineers/Society of Automotive Engineers/American Society of Electrical Engineers Joint Propulsion Conference and Exhibit.

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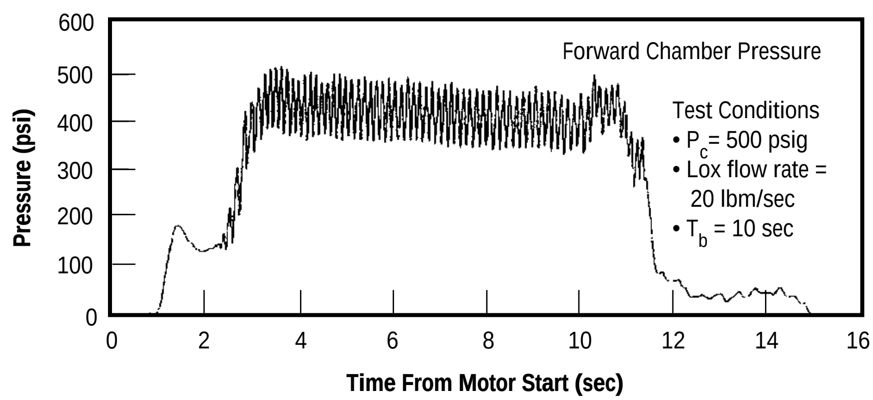

FIGURE 54.—Oscillations resulting from a coupling of motor and feed system.

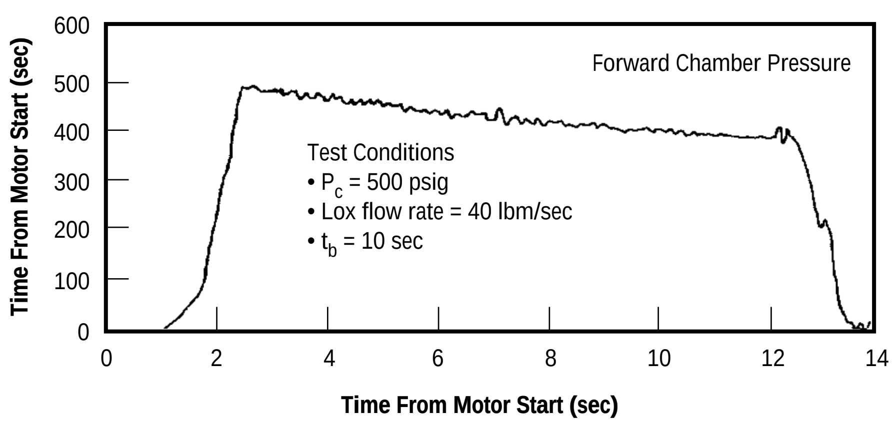

FIGURE 55.—Nonoscillatory combustion that occurs when isolation between motor and feed system is increased.